B.Tech thesis report on

Techno-Economic analysis of Bioethanol production from lignocellulosic residues: A process Simulation Approach

In partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Chemical Engineering

Submitted by

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Department of Chemical Engineering

2014

CERTIFICATE

This is to certify that the thesis entitled "**Techno-Economic analysis of Bioethanol production from lignocellulosic residues**: **A process Simulation Approach**" submitted by **Mr. Sourav Nanda (110CH0080)** in partial fulfilment of the requirements for the degree of Bachelor of Technology in Chemical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university or institute for the award of any degree.

Date:

Place: Rourkela

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ABSTRACT

The present work reports the technical analysis of bioethanol production from lignocellulosic residues like empty fruit brunches, rice husks & sugar cane bagasse. The ethanol production was figured utilizing aspen plus. The composition of the three feedstocks i.e empty fruit brunches, rice husks and sugarcane baggase were required for simulation which was collected from the literature study and web. This process of producing bioethanol from lignocellulosic residues is more economical than producing bioethanol from maize or sugar cane. Among the three lignocellulosic residues considered Rice husk and Empty fruit brunches are cheaper compared to sugarcane baggase and have high yield value of ethanol i.e 0.52 and 0.38 respectively. However the sugarcane baggase are comparatively costlier and have low yield value of ethanol. Due to their abundant availability and cheaper purchase price the lignocellulosic residues are more economical when compared to the conventional way of producing ethanol.

Keywords: Lignocellulosic, Bioethanol, Empty fruit brunches, Rice husks, Sugarcane baggasse, maize

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NOMENCLATURE

SCB – Sugarcane bagasse

EFB – Empty fruit brunches

RS – Rice husks

SFEED – Standard feed

HYDRA – Hydrolysis tank

SEPARATR – Separator for separation of Solid glucose fraction and liquid xylose

EVA – Evaporator

HE – Heat Exchanger

DETREA – Detoxification reactor

NEUTREA – Neutralization reactor

GYSEPA – Gypsum separator

GLUCONC – Enzymatic glucose concentration reactor

EVA2 – Evaporator

FERMREA – Fermentation reactor

ConcREA – Concentration reactors

VAP – Vapours

SOLFRAC- Solid glucose and lignin fraction

CONCXYL – Concentrated xylose

23 – Broth

B28 – Centrifuge

ETHA - Ethanol

CONCETHA – Concentrated ethanol

CHAPTER 1
INTRODUCTIONS

There has been a rapid growth in industrialization and hence global demand for bioethanol is increasing. Conventional crops such as corn and sugarcane are unable to meet the global demand of bioethanol production as these are also used as food and high purchase price of feed. Therefore, lignocellulosic residues like agricultural wastes are attractive feedstocks for bioethanol production due to their vast availability and cheaper purchase price. Bioethanol can be used as vehicle fuel and it has octane booster capacity and compared to other fuel it emits less carbon monoxide.

1.1 – Lignocellulosic Residues :

Lignocellulose is a complex polymer having high composition of 3 carbohydrates cellulose, hemicellulose and lignin. Lignocellulosic residues are available in large amount and thus it is considered as an attractive feedstock for the production of fuel ethanol.

Lignocellulosic residues can be broadly classified into 3 type

(i) Virgin Biomass
(ii) Waste Biomass
(iii) Energy Crops

1.2 – Types of Lignocellulosic residues

In general lignocellulosic residues for fuel ethanol production can be classified into six major groups

(i) Crop Residues
e.g Cane baggase, Corn storer, Wheat Straw, rice straw, rice bulls, barley straw, sweet sorghum bagasse, olive stones & pulp

(ii) Hard wood
Aspen, Poplar

(iii) Soft wood
Pine, Spruce

(iv) Cellulose Wastes
News print, Waste office paper, recycled paper sludge

(v) Herbaceous biomass

Alfalfa hay, switch grass , reed canary grass, coastal Bermuda grass

(vi) Municipal solid wastes

Numerous studies for developing large-scale production of ethanol from lignocellulosics have been carried out in many countries. But, the main restricting factor is the high degree of complexity inherent to the processing of lignocellulosic feeds. Its related to the type & composition of lignocellulosic feedstock (which contain up to 75% of cellulose and hemicelluloses). Hollocellulosic components should be converted into fermentable sugars in order to be converted into ethanol or other valuable products (e.g. xylans, xylitol, hydrogen and enzymes), following the growing biorefinery concept (Moncada et al., 2013; Njoku et al., 2012; Rabelo et al., 2011). But this degradation process is complicated, energy-consuming and noncompletely developed. With the use of modern genetics and other tools the cost of producing sugars from these recalcitrant fractions and converting them into products such as ethanol can be significantly reduced in the future. Many thesis have been published on the theme of fuel ethanol production especially from lignocellulosic biomass.

In this work, 3 lignocellulosic materials were considered in order to evaluate the viability of the production of fuel ethanol process. These consists in sugarcane bagasse (SCB), empty fruit bunches (EFB), rice husk (RH). The chemical composition of these materials was determined experimentally. The chemical composition was also used as the starting point in the simulation of the process to obtain fuel ethanol from the 3 lignocellulosic raw materials (i.e. SCB, EFB, RH). Ethanol production process was simulated using Aspen Plus and Aspen Economic Analyzer software, in order to determine the production cost. Dilute acid was considered in the process simulation as the technology for the pretreatment of the lignocellulosic residues. Given this, the aim of this work is to compare, from the techno-economic point of view, different lignocellulosic crop residues to produce fuel ethanol.

CHAPTER 2
LITERATURE REVIEW

The 3 different types of lignocellulose materials considered for this process are sugar cane bagasse (SCB), empty fruit brunches (EFB), rice husks (RH).

2.1 Characterization of raw materials:

To find out the cellulose, hemicellulose & lignin content of the crude materials, these are artificially portrayed. The moisture content can be found out by drying the materials to consistent weight. The distinction in the weight gives moisture content. The extractions are dead set utilizing toluene – ethanol mixture at 45degree C for 24 hrs focused around TAPPI standard. Lignin substance can be figured out by including klasnon lignin and acid dissolvable lignin. Cellulose and hemicellulose substance is resolved with the chlorination strategy depicted by ASTM standard D1104.

2.2 Process description:

2.2.1 Fuel Ethanol Production

The assessment of fuel ethanol generation from EFB, SCB, RH considered both specialized and monetary perspectives. In the present work, the calculation of the creation cost was performed to overview the gainfulness of fuel ethanol generation utilizing every unrefined material. To achieve this, the mass and vitality parities registered using procedure recreation instruments, are the starting stage to center the capital and working costs. The last furthermore serves as the reason to center the monetary examination of the generation of fuel ethanol from all lignocellulosic residue (i.e. EFB, SCB, RH). Fig. 1 is the disentangled methodology stream sheet for the creation of fuel ethanol utilized as a part of this work. It contains 5 principle stages: pretreatment with weaken acid detoxification, enzymatic saccharification, fermentation and separation.

Steam explosion is an ensuring framework for pretreatment which makes biomass more open to cellulase strike. This framework for pretreatment without the use of any impetus is ensuring and the biomass fractionates to yield levulinic acids, xylitol and alcohols. In this framework the biomass is warmed using highpressure steam (20-50 bar, 160-290 C) for a few minutes; the reaction is then ended by sudden decompression to environmental weight. Right when steam is allowed to extend inside the lignocellulosic lattice it differentiates the

individual strands. The high recuperation of xylose (45-65%) makes steam-explosion pretreatment monetarily alluring.

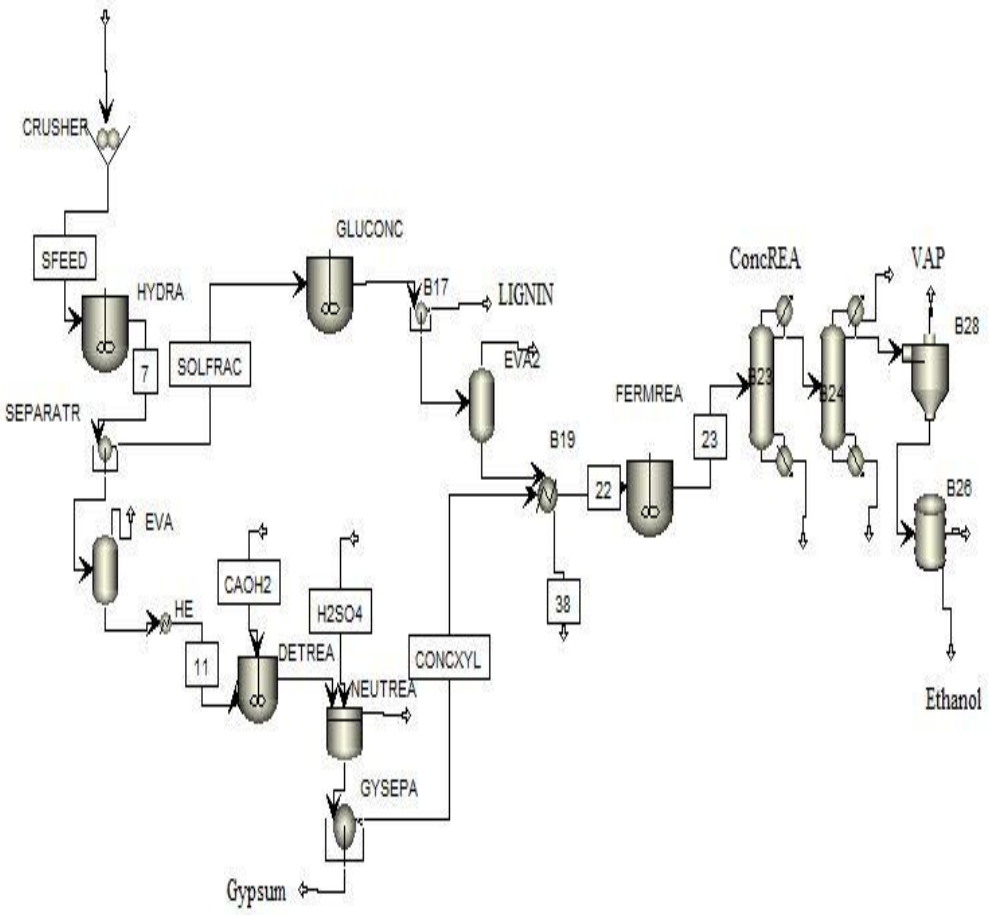
Acid pretreatment is considered as a standout amongst the most essential methods and goes for significant returns of sugars from lignocellulosics. It is typically done by concentrated or weakened acids (for the most part somewhere around 0.2% and 2.5% w/w) at temperatures between 130 C and 210 C. Sulfuric acid is broadly utilized for acid pretreatment among different sorts of acid, for example, hydrochloric acid, nitric acid and phosphoric acid. Acid pretreatment can use either weaken or concentrated acids to enhance cellulose hydrolysis. The acid medium assaults the polysaccharides, particularly hemicelluloses which are simpler to hydrolyze than cellulose. Notwithstanding, acid pretreatment brings about the generation of different inhibitors like acidic acid, furfural and 5 hydroxymethylfurfural. These items are development inhibitors of microorganisms. Hydrolysates to be utilized for maturation consequently need to be detoxified. Moise reported higher hydrolysis yield from lignocellulose pretreated with weakened H_2SO_4 contrasted with different acids.

Degradation of the lignocellulosic complex to free cellulose can be realized with the assistance of microorganisms like brown decay, white decay and delicate decay organisms. Organic pretreatment renders the degradation of lignin and hemicellulose and white decay parasites appear to be the best microorganism. Brown decay assaults cellulose while white and delicate decays assault both cellulose and lignin. Cellulase-less mutant was produced for the particular degradation of lignin and to keep the loss of cellulose yet by and large of organic pretreatment the rate of hydrolysis is low. This system is sheltered and vitality sparing because of less mechanical backing. It needs no chemicals however low hydrolysis rates and low yields obstruct its usage. Organic pretreatment of bamboo culms with white decay growths has been performed at low temperature (25 C). On account of a marine microorganism Phlebia sp. MG-60, it was seen that when the substrate was supplemented with a supplement medium, for example, Kirk's Medium, better delignification was watched contrasted with sanitized water. Bio-delignification for the most part needs drawn out stretches of time.

Saccharification is the discriminating venture for bioethanol creation where complex sugars are changed over to basic monomers. Contrasted with corrosive hydrolysis, enzymatic hydrolysis requires less vitality and gentle environment conditions. The ideal conditions for

cellulase have been accounted for as temperature of 40-50 C and ph 4-5. Test conditions for xylanase have likewise been accounted for to be 50 C temperature and ph 4-5 Therefore, enzymatic hydrolysis is invaluable on account of its low danger, low utility cost and low erosion contrasted with corrosive or antacid hydrolysis.. Additionally, no inhibitory by-item is structured in enzymatic hydrolysis. Then again, enzymatic hydrolysis is completed by cellulase compounds that are exceedingly substrate particular. Here cellulase and hemicellulase catalysts sever the bonds of cellulose and hemicellulose individually. Cellulose is hydrolysed to glucose while hemicellulose gives rise to several pentoses and hexoses. Several species of Clostridium, Cellulomonas, Thermonospora, Bacillus, Bacteriodes, Ruminococcus, Erwinia, Acetovibrio, Microbispora, and Streptomyces are able to produce cellulase enzyme. Many fungi such as Trichoderma, Penicillium, Fusarium, Phanerochaete, Humicola, Schizophillum sp. also have been reported for cellulose production. Various factors influence yields of monomer sugars from lignocellulose. Temperature, pH and mixing rate are the main factors of enzymatic hydrolysis of lignocellulosic material. Other factors that affect yield are substrate concentration, cellulose enzyme loading, and surfactant addition. High substrate concentration may lead to substrate inhibition. Cellulase contributes to the major cost of the lignocellulosic ethanol technology. Therefore, an efficient pretreatment is to be selected to decrease cellulose crystallinity and to remove lignin to the maximum extent, so that hydrolysis time as well as cellulase loading will be minimized. Surfactants modify the cellulose surface by adsorbing lignin onto surfactant and thus the surfactant prevents the enzyme from unproductive binding with lignin and lowers enzyme loading. Several studies have been reported on the conversion of cellulosic biomass to sugars by enzymatic hydrolysis.

The saccharified biomass is used for fermentation by several microorganisms. But the industrial utilization of lignocelluloses for bioethanol production is hindered by the lack of ideal microorganisms which can efficiently ferment both pentose and hexose sugars.



[Fig 1 – Flowsheet of ethanol plant considered]

CHAPTER 3
ASPEN PLUS SIMULATION PROCEDURE

The simulation was performed using aspen plus software. The temperature and yield data used in simulation for various reactors and stream of the above flowsheet is explained below. NRTL property method is used in simulation.

3.1 Procedure Description:-

First molecular size reduction of the feed is done, where the normal width of 1 mm is achieved. In the wake of processing and sieving, the lignocellulosic material is subjected to a weak acid hydrolysis (200^{0}C for 4 h), which permits the change of hemicellulose into pentoses (mainly xylose). Furfural, hydroxymethylfurfural (HMF) and natural acids are side effects of this methodology. In the detoxification stage, the fluid portion (hemicellulose hydrolysate) that came about because of the pretreatment methodology is treated with $Ca(OH)_2$ at 60 ^{0}C for 30 min. This step is considered to diminish the convergence of furfural and HMF, which are inhibitory mixes for further fermentation.

At that point, the stream out of the detoxification is treated with sulfuric acid. The strong part coming out because of the pretreatment process (mainly cellulose and lignin) is treated with celluloses to change over robust cellulose into hexoses at 50 ^{0}c for 96 h. At long last, the streams of lessening sugars (cellulose and hemicellulose hydrolysates) are blended and prepared for fermentation process.

Fermentation is the main step in ethanol production process. The reducing sugars streams i.e glucose and xylose coming from the previous stages are converted into ethanol by a recombinant bacterium Zymomonas mobilis at 33^{0}C for 30 h. This recombinant bacteria, has the ability to uptake hexose as carbon source or a combination of a hexose–pentose mixture. Broth containing 7-10% ethanol is formed after fermentation and is sent to the separation zone with 2 distillation columns where at first ethanol is concentrated upto 50-55% and then upto 90% respectively. After dehydration 99.7% is obtained as final product.

Estimation of energy consumption was conducted based on the simulation data of thermal energy required by the heat exchangers, reboilers and related units. Batch reactors were used to simulate acid pretreatment and detoxification, sugar fermentation. Hydrolysis was

simulated using a stoichiometric approach that considered the conversion of cellulose into glucose without the kinetic models.

3.2 Physical Property Data of components :

Physical property data for all the components to be used in simulation were obtained from Wooley and Pusche (1996) and are given in the table below.

Table 1: Physical property data of components

Name	**Formula**	**State**
Moisture	H_20	Liquid
Cellulose	$C_6H_{12}O_5$	Solid
Xylan	$C_5H_8O_4$	Solid
Lignin	$C_{7.3}H_{13.9}O_{1.3}$	Solid
Biomass	$CH_{1.64}N_{0.23}O_{0.39}S_{0.0035}$	Solid
Protein	NH_2 CHRCOOH	Solid

3.2.1 Combustion stoichiometry :-

For cellulose :

$C_6H_{10}O_5 + 6\ O_2 \rightarrow 5\ H_20 + 6\ CO_2$

For Hemicellulose :

$C_5H_8O_4 + 6\ O_2 \rightarrow 4\ H_2O + 6\ CO_2$

For Glucose :

$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ H_2O + 6\ CO_2$

For Xylose :

$C_5H_{10}O_5 + 5\ O_2 \rightarrow 5\ H_2O + 5\ CO_2$

In hydrolysis the big molecules of cellulose and hemicellulose are converted into small sugar molecules like glucose ($C_6H_{12}O_6$) and xylose ($C_5H_{10}O_5$).

All C_{6-} sugars exhibit almost same type of properties throughout the entire process with each other and so does all C_5 - sugars with each other. So only glucose and xylose are considered as the sugars converting into ethanol.

4.1 Chemical composition of lignocellulosic residues:

In most of the materials, cellulose was the main component with more than 30% (i.e. SCB, EFB). The holocellulosic (cellulose and hemicellulose) complex represents more than 50% of the total dry weight for all residues. It can be inferred that all residues have a high potential for the recovery of sugars from hemicellulose and cellulose (pentose and hexose). Nevertheless, the high lignin and ash contents of rice husk could represent a limiting characteristic.

Chemical composition of lignocellulosic residues considered for this work i.e RH, EFB and SCB is given in this following table.

Table 2: Chemical Composition of the feeds considered

Components	RS	EFB	SCB
Moisture	16	65	52
Cellulose	28.03	44	42.60
Hemicellulose	29.20	28.24	24.8
Lignin	28.6	16.19	19.5
Extractives	1.35	6.2	7
Protein	1.65	3.05	2.1
Ash	11.17	2.32	4

Compositions are calculated on dry basis.

There are other significant aspects that directly affect the potential of fuel ethanol production. High moisture content might suggest a higher flow rate of fresh (wet) material to produce ethanol. In this sense, as shown in Table 2 SCB and EFB have high moisture content, which is above 50%. The latter is significantly relevant to be considered in the production process, since this advises about different alternatives to process the raw material, dried or wet. This also depends on different logistics aspects as collection and transportation of these residues. High moisture content also must be considered as very important, since most of the degradation processes are faster in presence of water. In the case of RH, it can be seen that the moisture content is 16%. These aspects are thoroughly discussed in the following section. Besides, protein and extractives, which can be defined as fats, fatty acids, phenols, among other compounds, are in quite less proportion than the rest and its interfering effect can most probably be neglected.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Simulation Results:

Simulation was performed and the following results were obtained.

Simulation results for feed Rice Husks:

1 : Hydrolysis section

The lignocellulosic material is subjected to a dilute acid hydrolysis stage (135 C for 4 h), which allows the conversion of cellulose and hemicellulose into glucose (DEXTR-01) and pentoses (mainly xylose DIETH-01). Lignin is obtained as a solid fraction along with the glucose content, whereas xylose is obtained in liquid form. Result of the hydrolysis section is shown below. Amount of glucose ,lignin and xylose leaving hydrolysis section is 1.554, 3.016 and 3.622 kmol/hr respectively.

Fig 2 : Simulation results for feed Rice Husks (Hydrolysis section)

Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

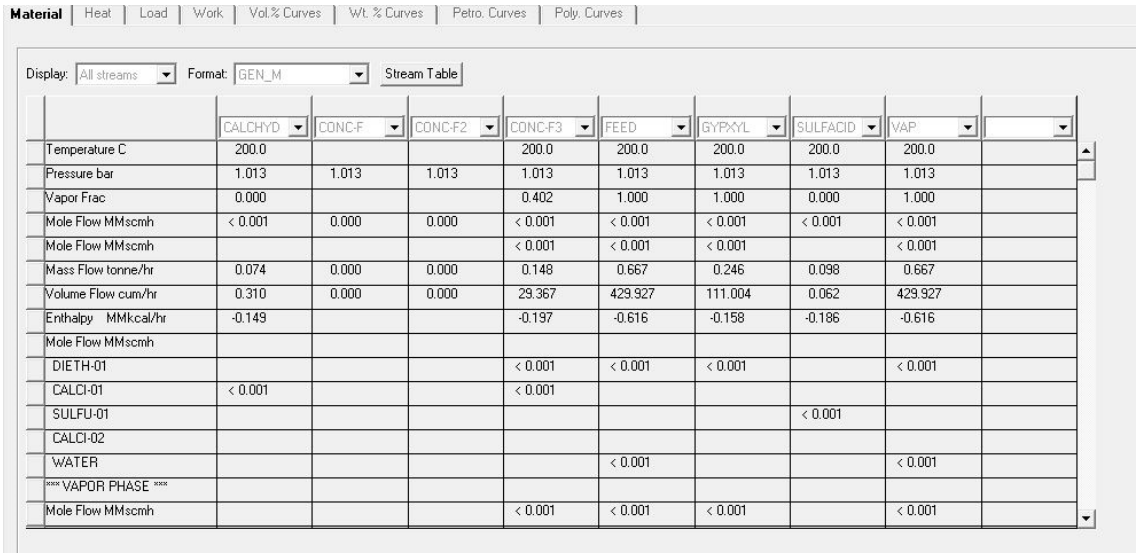
Display: All streams Format: GEN_M Stream Table

	GLUXYL	RS	
Temperature C	200.0	200.0	
Pressure bar	25.000	1.013	
Vapor Frac	0.000	0.450	
Mole Flow kmol/hr	10.413	14.175	
Mass Flow kg/hr	1000.000	1000.000	
Volume Flow cum/hr	0.983	248.391	
Enthalpy MMkcal/hr	-0.675	-1.465	
Mole Flow			
WATER	2.220	7.771	
DILAC-01		1.480	
GLUTA-01		1.907	
DEXTR-01	1.554		
DIETH-01	3.622		
LIGNIN	3.016	3.016	

2. Evaporation and Xylose Concentration section

In this section the liquid xylose coming from hydrolysis of lignocellulosic materials is concentrated. Around 40-60% xylose is recovered. From the neutralization reactor, gypsum is obtained as a byproduct.

Fig 3 : Simulation results for feed Rice Husks (Evaporation and Xylose Concentration section)



Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

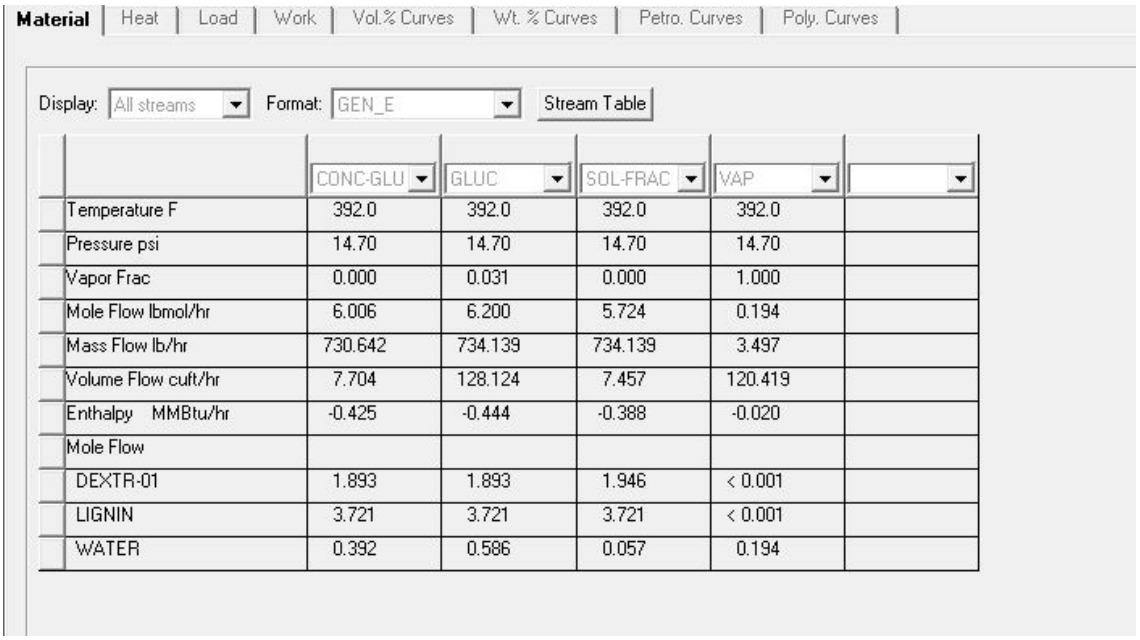
Display: All streams Format: GEN_M Stream Table

	CALCHYD	CONC-F	CONC-F2	CONC-F3	FEED	GYPXYL	SULFACID	VAP	
Temperature C	200.0			200.0	200.0	200.0	200.0	200.0	
Pressure bar	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	
Vapor Frac	0.000			0.402	1.000	1.000	0.000	1.000	
Mole Flow MMscmh	< 0.001	0.000	0.000	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	
Mole Flow MMscmh				< 0.001	< 0.001	< 0.001		< 0.001	
Mass Flow tonne/hr	0.074	0.000	0.000	0.148	0.667	0.246	0.098	0.667	
Volume Flow cum/hr	0.310	0.000	0.000	29.367	429.927	111.004	0.062	429.927	
Enthalpy MMkcal/hr	-0.149			-0.197	-0.616	-0.158	-0.186	-0.616	
Mole Flow MMscmh									
DIETH-01				< 0.001	< 0.001	< 0.001		< 0.001	
CALCI-01	< 0.001			< 0.001					
SULFU-01							< 0.001		
CALCI-02									
WATER					< 0.001			< 0.001	
*** VAPOR PHASE ***									
Mole Flow MMscmh				< 0.001	< 0.001	< 0.001		< 0.001	

3. Glucose Concentration section

In this section Saccharification of glucose occurs. Lignin is separated from glucose and concentrated glucose is fed to fermentation section. Results are shown below.

Fig 4 : Simulation results for feed Rice Husks (Glucose Concentration section)



Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

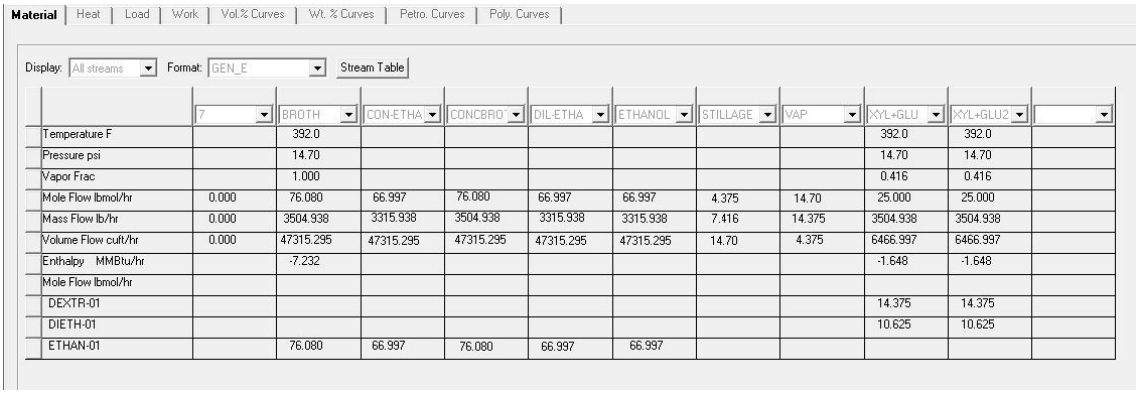
Display: All streams Format: GEN_E Stream Table

	CONC-GLU	GLUC	SOL-FRAC	VAP	
Temperature F	392.0	392.0	392.0	392.0	
Pressure psi	14.70	14.70	14.70	14.70	
Vapor Frac	0.000	0.031	0.000	1.000	
Mole Flow lbmol/hr	6.006	6.200	5.724	0.194	
Mass Flow lb/hr	730.642	734.139	734.139	3.497	
Volume Flow cuft/hr	7.704	128.124	7.457	120.419	
Enthalpy MMBtu/hr	-0.425	-0.444	-0.388	-0.020	
Mole Flow					
DEXTR-01	1.893	1.893	1.946	< 0.001	
LIGNIN	3.721	3.721	3.721	< 0.001	
WATER	0.392	0.586	0.057	0.194	

4. Fermentation Section

The reducing sugars streams coming from the previous stages are converted into ethanol by a recombinant bacterium Zymomonas mobilis at 33 C for 30 h. 99.7% (w/w) ethanol is produced. Result is shown below.

Fig 5 : Simulation results for feed Rice Husks (Fermentation Section)



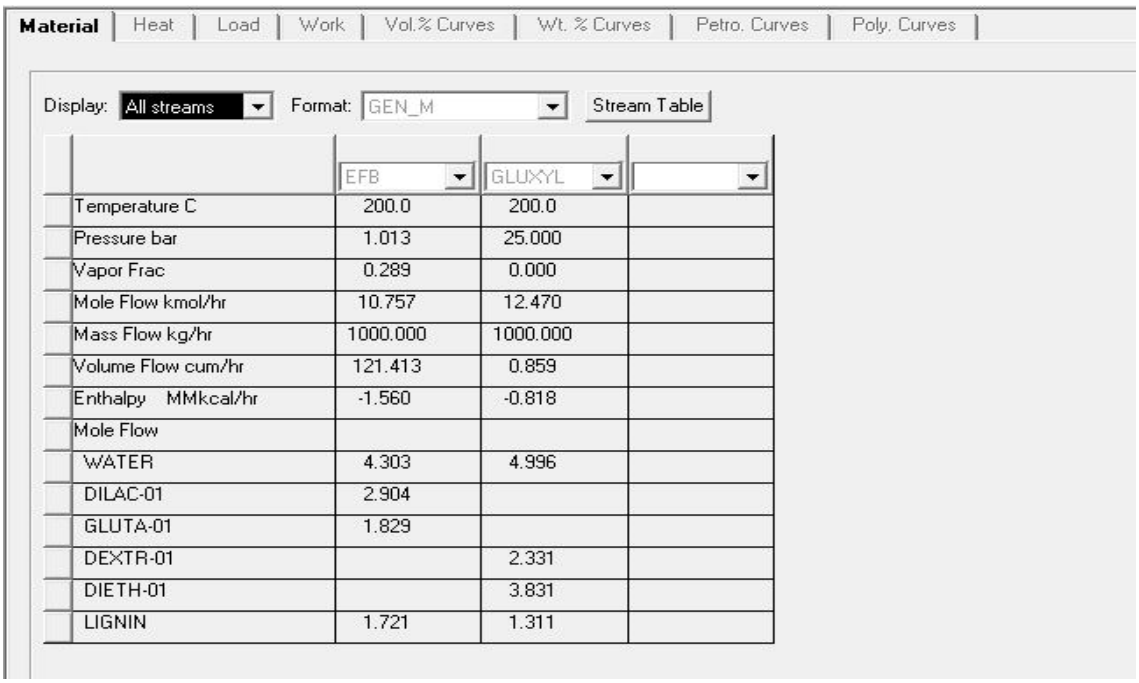
Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	7	BROTH	CON-ETHA	CONCBRO	DIL-ETHA	ETHANOL	STILLAGE	VAP	XYL+GLU	XYL+GLU2	
Temperature F		392.0							392.0	392.0	
Pressure psi		14.70							14.70	14.70	
Vapor Frac		1.000							0.416	0.416	
Mole Flow lbmol/hr	0.000	76.080	66.997	76.080	66.997	66.997	4.375	14.70	25.000	25.000	
Mass Flow lb/hr	0.000	3504.938	3315.938	3504.938	3315.938	3315.938	7.416	14.375	3504.938	3504.938	
Volume Flow cuft/hr	0.000	47315.295	47315.295	47315.295	47315.295	47315.295	14.70	4.375	6466.997	6466.997	
Enthalpy MMBtu/hr		-7.232							-1.648	-1.648	
Mole Flow lbmol/hr											
DEXTR-01									14.375	14.375	
DIETH-01									10.625	10.625	
ETHAN-01		76.080	66.997	76.080	66.997	66.997					

Simulation results for EFB :

1. Fig 6 Simulation results for EFB (Hydrolysis section)

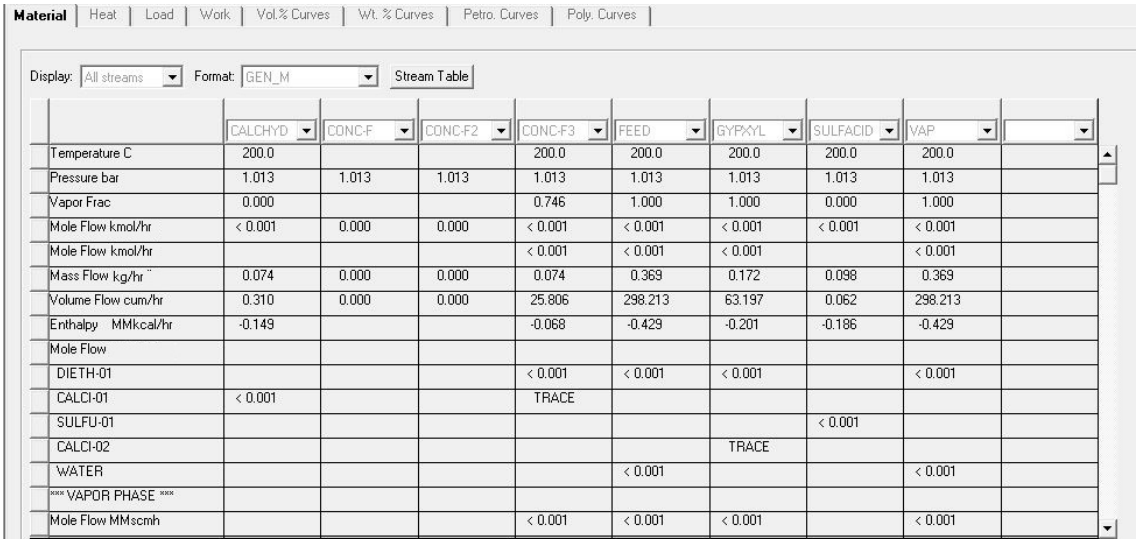


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_M Stream Table

	EFB	GLUXYL	
Temperature C	200.0	200.0	
Pressure bar	1.013	25.000	
Vapor Frac	0.289	0.000	
Mole Flow kmol/hr	10.757	12.470	
Mass Flow kg/hr	1000.000	1000.000	
Volume Flow cum/hr	121.413	0.859	
Enthalpy MMkcal/hr	-1.560	-0.818	
Mole Flow			
WATER	4.303	4.996	
DILAC-01	2.904		
GLUTA-01	1.829		
DEXTR-01		2.331	
DIETH-01		3.831	
LIGNIN	1.721	1.311	

2. Fig 7 Simulation results for EFB (Evaporation and Xylose Concentration section)

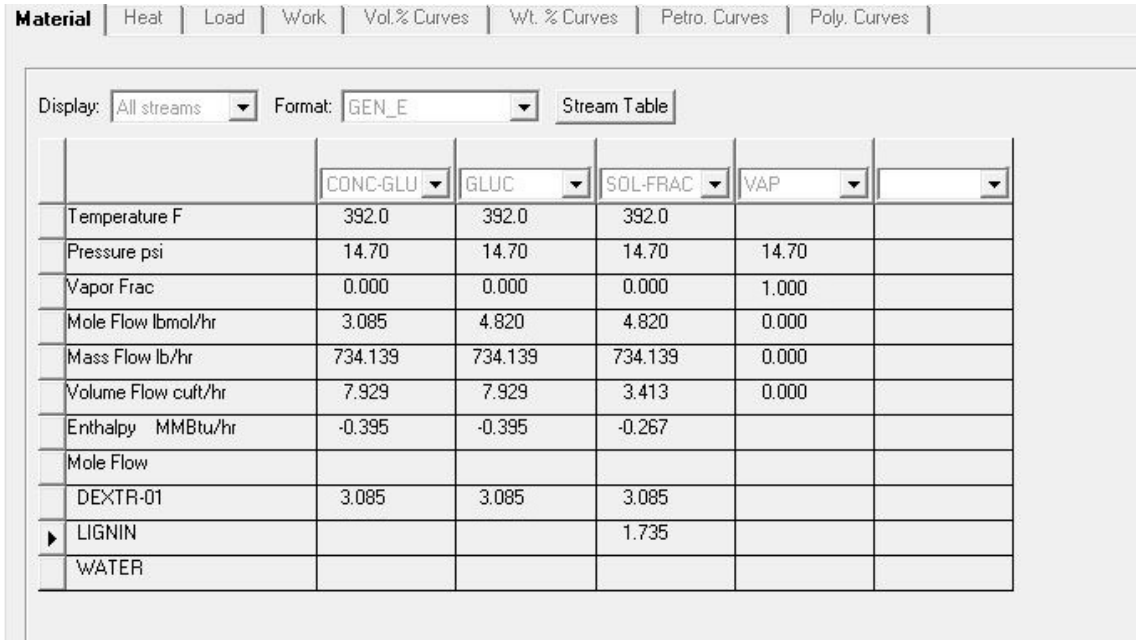


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_M Stream Table

	CALCHYD	CONC-F	CONC-F2	CONC-F3	FEED	GYPXYL	SULFACID	VAP	
Temperature C	200.0			200.0	200.0	200.0	200.0	200.0	
Pressure bar	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	
Vapor Frac	0.000			0.746	1.000	1.000	0.000	1.000	
Mole Flow kmol/hr	< 0.001	0.000	0.000	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	
Mole Flow kmol/hr				< 0.001	< 0.001	< 0.001		< 0.001	
Mass Flow kg/hr	0.074	0.000	0.000	0.074	0.369	0.172	0.098	0.369	
Volume Flow cum/hr	0.310	0.000	0.000	25.806	298.213	63.197	0.062	298.213	
Enthalpy MMkcal/hr	-0.149			-0.068	-0.429	-0.201	-0.186	-0.429	
Mole Flow									
DIETH-01				< 0.001	< 0.001	< 0.001		< 0.001	
CALCI-01	< 0.001			TRACE					
SULFU-01							< 0.001		
CALCI-02						TRACE			
WATER					< 0.001			< 0.001	
**** VAPOR PHASE ****									
Mole Flow MMscmh				< 0.001	< 0.001	< 0.001		< 0.001	

3. Fig 8 Simulation results for EFB (Glucose concentration section)

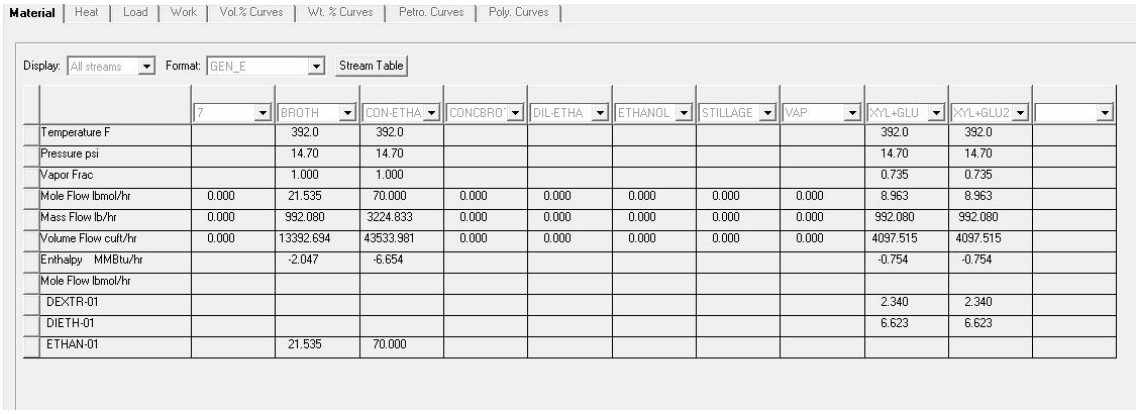


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	CONC-GLU	GLUC	SOL-FRAC	VAP	
Temperature F	392.0	392.0	392.0		
Pressure psi	14.70	14.70	14.70	14.70	
Vapor Frac	0.000	0.000	0.000	1.000	
Mole Flow lbmol/hr	3.085	4.820	4.820	0.000	
Mass Flow lb/hr	734.139	734.139	734.139	0.000	
Volume Flow cuft/hr	7.929	7.929	3.413	0.000	
Enthalpy MMBtu/hr	-0.395	-0.395	-0.267		
Mole Flow					
DEXTR-01	3.085	3.085	3.085		
LIGNIN			1.735		
WATER					

4. Fig 9 Simulation results for EFB (Fermentation Section)



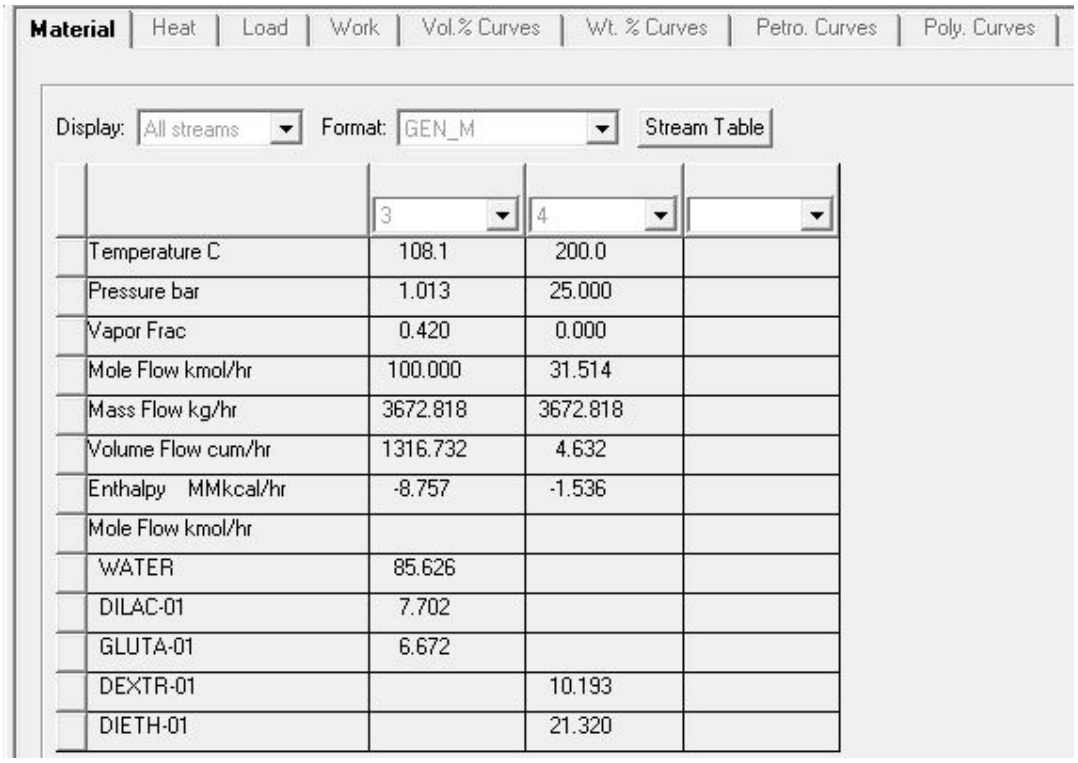
Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	7	BROTH	CON-ETHA	CONCBRO	DIL-ETHA	ETHANOL	STILLAGE	VAP	XYL+GLU	XYL+GLU2	
Temperature F		392.0	392.0						392.0	392.0	
Pressure psi		14.70	14.70						14.70	14.70	
Vapor Frac		1.000	1.000						0.735	0.735	
Mole Flow lbmol/hr	0.000	21.535	70.000	0.000	0.000	0.000	0.000	0.000	8.963	8.963	
Mass Flow lb/hr	0.000	992.080	3224.833	0.000	0.000	0.000	0.000	0.000	992.080	992.080	
Volume Flow cuft/hr	0.000	13392.694	43533.981	0.000	0.000	0.000	0.000	0.000	4097.515	4097.515	
Enthalpy MMBtu/hr		-2.047	-6.654						-0.754	-0.754	
Mole Flow lbmol/hr											
DEXTR-01									2.340	2.340	
DIETH-01									6.623	6.623	
ETHAN-01		21.535	70.000								

Simulation results for SCB :

1. Fig 10 Simulation results for SCB (Hydrolysis section)

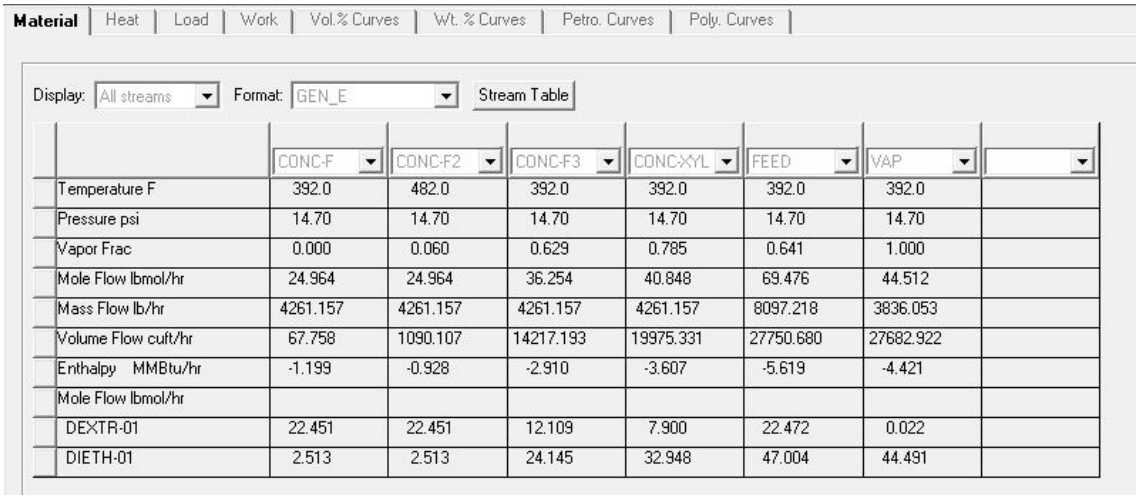


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_M Stream Table

	3	4	
Temperature C	108.1	200.0	
Pressure bar	1.013	25.000	
Vapor Frac	0.420	0.000	
Mole Flow kmol/hr	100.000	31.514	
Mass Flow kg/hr	3672.818	3672.818	
Volume Flow cum/hr	1316.732	4.632	
Enthalpy MMkcal/hr	-8.757	-1.536	
Mole Flow kmol/hr			
WATER	85.626		
DILAC-01	7.702		
GLUTA-01	6.672		
DEXTR-01		10.193	
DIETH-01		21.320	

2. Fig 11 Simulation results for SCB (Evaporation and Xylose concentration section)

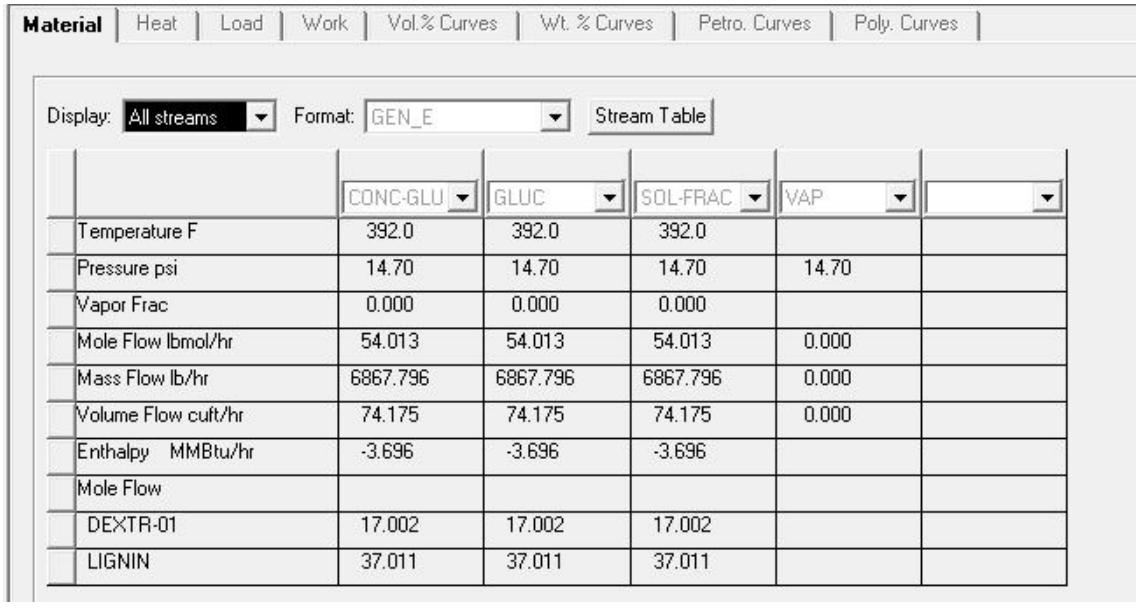


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	CONC-F	CONC-F2	CONC-F3	CONC-XYL	FEED	VAP	
Temperature F	392.0	482.0	392.0	392.0	392.0	392.0	
Pressure psi	14.70	14.70	14.70	14.70	14.70	14.70	
Vapor Frac	0.000	0.060	0.629	0.785	0.641	1.000	
Mole Flow lbmol/hr	24.964	24.964	36.254	40.848	69.476	44.512	
Mass Flow lb/hr	4261.157	4261.157	4261.157	4261.157	8097.218	3836.053	
Volume Flow cuft/hr	67.758	1090.107	14217.193	19975.331	27750.680	27682.922	
Enthalpy MMBtu/hr	-1.199	-0.928	-2.910	-3.607	-5.619	-4.421	
Mole Flow lbmol/hr							
DEXTR-01	22.451	22.451	12.109	7.900	22.472	0.022	
DIETH-01	2.513	2.513	24.145	32.948	47.004	44.491	

3. Fig 12 Simulation results for SCB (Glucose concentration section) :

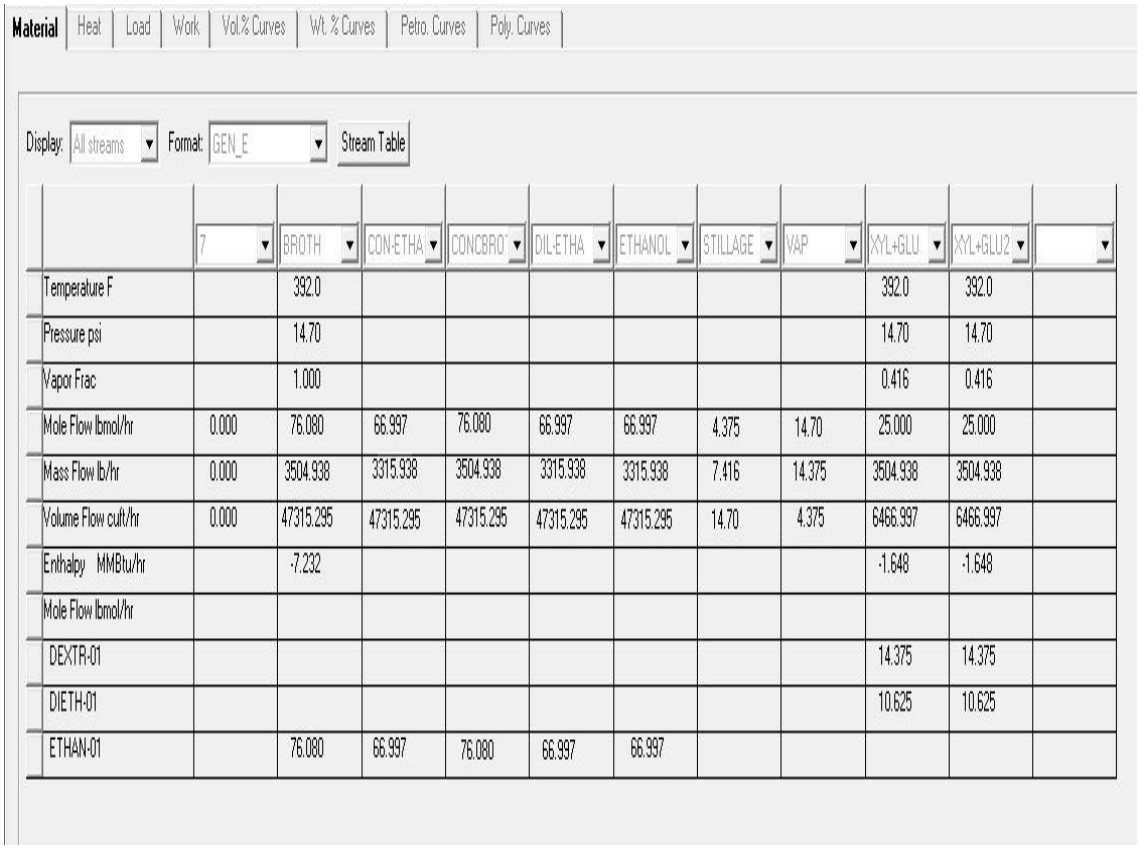


Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	CONC-GLU	GLUC	SOL-FRAC	VAP	
Temperature F	392.0	392.0	392.0		
Pressure psi	14.70	14.70	14.70	14.70	
Vapor Frac	0.000	0.000	0.000		
Mole Flow lbmol/hr	54.013	54.013	54.013	0.000	
Mass Flow lb/hr	6867.796	6867.796	6867.796	0.000	
Volume Flow cuft/hr	74.175	74.175	74.175	0.000	
Enthalpy MMBtu/hr	-3.696	-3.696	-3.696		
Mole Flow					
DEXTR-01	17.002	17.002	17.002		
LIGNIN	37.011	37.011	37.011		

4. Fig 12 Simulation results for SCB (Fermentation section) :



Material | Heat | Load | Work | Vol.% Curves | Wt. % Curves | Petro. Curves | Poly. Curves

Display: All streams Format: GEN_E Stream Table

	7	BROTH	CON-ETHA	CONCBRO	DIL-ETHA	ETHANOL	STILLAGE	VAP	XYL+GLU	XYL+GLU2	
Temperature F		392.0							392.0	392.0	
Pressure psi		14.70							14.70	14.70	
Vapor Frac		1.000							0.416	0.416	
Mole Flow lbmol/hr	0.000	76.080	66.997	76.080	66.997	66.997	4.375	14.70	25.000	25.000	
Mass Flow lb/hr	0.000	3504.938	3315.938	3504.938	3315.938	3315.938	7.416	14.375	3504.938	3504.938	
Volume Flow cuft/hr	0.000	47315.295	47315.295	47315.295	47315.295	47315.295	14.70	4.375	6466.997	6466.997	
Enthalpy MMBtu/hr		-7.232							-1.648	-1.648	
Mole Flow lbmol/hr											
DEXTR-01									14.375	14.375	
DIETH-01									10.625	10.625	
ETHAN-01		76.080	66.997	76.080	66.997	66.997					

For 4000kg/hr of feed (SCB) supplied , approximately 3315 lb/hr of ethanol is produced. The yield ratio for SCB is 0.376 or 37.6%.

In case of RS and EFB 1000kg/hr of feed was considered and their yield ratio was found to be 0.52 and 0.38 respectively.

Table 3: Feed cost and respective Ethanol Yield

Feed	Cost per ton (in $)	Yield (Ethanol produced/Feed Supplied)
SCB	15	0.367
RS	5	0.52
EFB	5	0.38

4.2 Discussion:

It was noticed that with change in composition of feeds, the value of ethanol produced changes. Other factors affecting the bioethanol production can be the temperature and pressure in the reactors as well as the quality and efficiency of the reactors. Hydrolysis of the raw material converts the large sugar molecules like cellulose and hemicellulose into small sugar molecules like glucose and xylose thus making it more convenient for the attack of yeast during fermentation. If the holocellulosic content i.e cellulose and hemicellulose content is higher, it indicates higher production of ethanol. Higher moisture content decreases the yield of ethanol. However the ash and other unwanted biomass present in the feeds can be neglected because they don't affect the production of ethanol much. Current methods used for production of bioethanol are not capable of converting lignin content into ethanol, hence it is separated from glucose after schharification. Recovery of xylose is a vital step in this process. 40-60% xylose recovery occurs here and gypsum is obtained as a byproduct. The ethanol produced is 99.7% (w/w) pure.

SCB feed costs more compared to the other two lignocellulosic residues considered i.e RS and EFB and has the lowest yield ratio because of low sugar conversion. However RS and EFB are cheaper than SCB but have higher yield percentage of ethanol. Pure bioethanol can be used as a vehicle fuel, but its mostly used as an additive to glycerine due to its octane booster capacity.

CHAPTER 5
CONCLUSIONS

The results showed that it is possible to produce bioethanol from sugarcane bagasse, empty fruit bunches, rice husks as raw materials. The ethanol yield depended on moisture content, the cellulose and hemicellulose content of the lignocellulosic residues, and the technology efficiency.

It can be seen from the results that change in feedstock changes the holocellulosic and moisture content and it changes the amount of bioethanol that can be produced. Sugarcane baggase was found to be the feed with lowest yield ratio of ethanol. Furthermore, the high cellulose and hemicellulose content, the low purchase price make rice husks the most economic residue to produce ethanol among other lignocellulosic residues. Empty fruit brunches are also a promising residue to produce ethanol because of cheaper purchase price.

Due to the vast availability and cheaper price of lignocellulosic residues, this method can be used instead of the conventional method of producing bioethanol i.e from maize or sugarcane etc. However for large industrial scale production of bioethanol using this method, suitable microorganism for fermentation aren't available. Genetically modified microorganisms can be used as ideal microorganisms for industrial scale bioethanol production using this method.

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